ANL/ESD/12-5
Rev. 2

Carbon Calculator for Land Use Change from Biofuels Production (CCLUB)

Users' Manual and Technical Documentation

Energy Systems Division

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Carbon **C**alculator for **L**and **U**se Change from **B**iofuels Production (CCLUB)

Users' Manual and Technical Documentation

by
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Version Notes

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1. Introduction

The Carbon Calculator for Land Use Change from Biofuels Production (CCLUB) calculates carbon emissions from land use change (LUC) for four different ethanol production pathways including corn grain ethanol and cellulosic ethanol from corn stover, *Miscanthus*, and switchgrass. This document discusses the version of CCLUB released September 30, 2014 which includes corn and three cellulosic feedstocks: corn stover, *Miscanthus*, and switchgrass.

Figure 1 outlines the calculations and data sources within CCLUB that are described in this document. Table 1 identifies where these data are stored and used within the CCLUB model, which is built in MS Excel. Land change area data is from Purdue University's Global Trade Analysis Project (GTAP) model, a computable general equilibrium (CGE) economic model. Section 2 describes the GTAP data CCLUB uses and how these data were modified to reflect shrubland transitions. Feedstock- and spatially-explicit belowground carbon content data for the United States were generated with a surrogate model for CENTURY's soil organic carbon sub-model (Kwon and Hudson 2010) as described in Section 3. CENTURY is a soil organic matter model developed by Parton *et al*. (1987). The version of CCLUB released in 2012 used CENTURY-derived carbon content data at the state level. Starting with the version released in 2013, CCLUB used soil carbon data at the county level for the United States. Aboveground non-soil carbon content data for forest ecosystems was sourced from the Carbon Online Estimator (COLE) (Van Deusen and Heath 2013). COLE is based on US Department of Agriculture Forest Service Inventory and Analysis and Resource Planning Assessment data, in addition to other ecological data, as explained in Section 4. COLE data are included in CCLUB at the county level. We discuss emission factors used for calculation of international greenhouse gas (GHG) emissions in Section 5. Temporal issues associated with modeling LUC emissions are the topic of Section 6. Finally, in Section 7 we provide a step-by-step guide to using CCLUB and obtaining results.

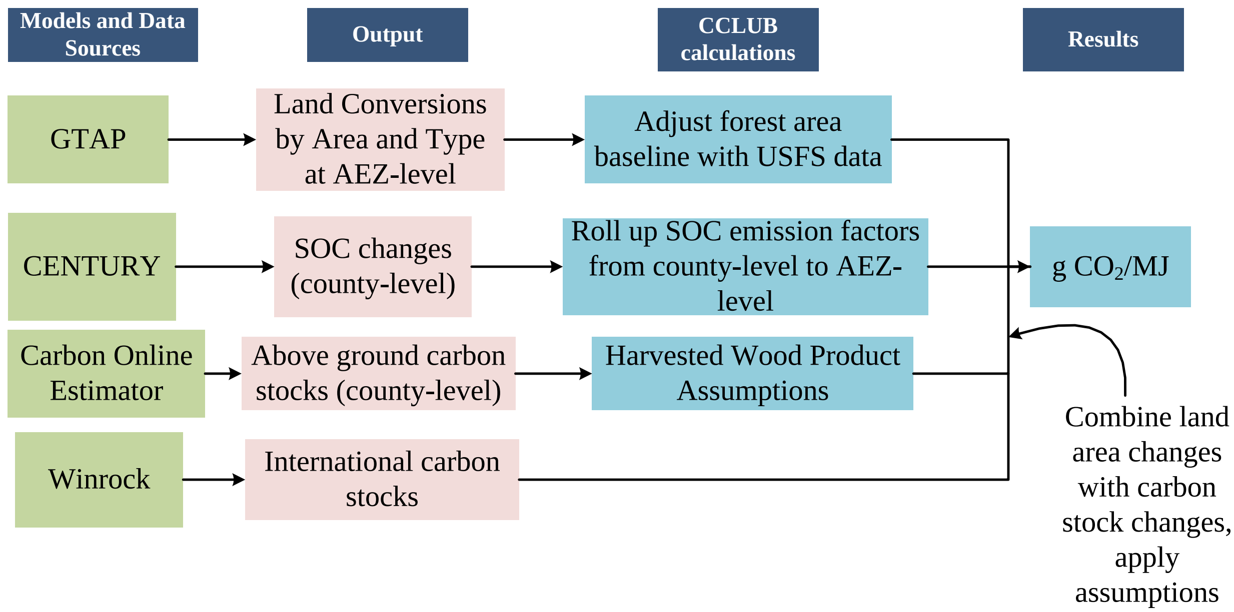

Figure 1. Schematic of Data Sources and Calculations in CCLUB. As explained in Section 5, Woods Hole data can be used as an alternative dataset to Winrock for international carbon stock.

Table 1. Overview of CCLUB Worksheets

Worksheet	Description
Scenario & Results	Displays results and enables selection of data sources, key assumptions, and biofuels scenarios
GTAP Data	Lists and summarizes GTAP source data
Modeling	Computes carbon emissions from land use change
Direct C-Factors	Derives carbon intensity factors for direct (domestic) land use
C-Database	Contains aboveground carbon and belowground carbon data at a county level for the United States
Indirect C-Factors	Derives carbon intensity factors for indirect (international) land use
Forest Factor	Computes forest correction factor for shrubland transitions

2. GTAP Data

CCLUB includes GTAP results from five different biofuel production scenarios. Each scenario reflects a shock to the economy in response to an increase demand for a biofuels feedstock commodity. The first four scenarios were modeled in 2011 (Taheripour *et al*. 2011). The fifth scenario was modeled in 2013 (Taheripour and Tyner 2013).

Table 2 lists the five production scenarios and associated biofuels volumes. The cellulosic ethanol scenarios (stover, switchgrass, *Miscanthus*) are modeled in GTAP as incremental production volumes on top of corn ethanol production.

Table 2. Biofuels Scenarios Modeled in CCLUB

Case[1]	Case Description	Gallons
A	An increase in corn ethanol production from its 2004 level (3.41 billion gallons [BG]) to 15 BG	11.59
E	An increase of ethanol from corn stover (i.e. AdvfE-Stover) by 9 BG, on top of 15 BG corn ethanol	9
F	An increase of ethanol from *Miscanthus* (i.e. AdvfE-Misc) by 7 BG, on top of 15 BG corn ethanol	7
G	An increase of ethanol from switchgrass (i.e. AdvfE-Swit) by 7 BG, on top of 15 BG corn ethanol	7
H	An increase in corn ethanol production from its 2004 level (3.41 BG) to 15 BG with GTAP recalibrated land transformation parameters	11.59

[1]Note: Case classifications A, E, F, and G refer to Taheripour *et al*. (2011). Case classification H refers to Taheripour and Tyner (2013)

The 2013 GTAP scenario shocked the production of corn ethanol by the same volume as the 2011 Case A scenario. These two modeling exercises, however, differ in the treatment of two key aspects of the GTAP model. First, in 2011, GTAP included one land transformation elasticity for the globe. Land transformation elasticity is a parameter that reflects the ease of land transition from one state to another; a low value indicates limited land transitions. Taheripour and Tyner (2013) used two United Nations Food and Agriculture Organization (FAO) land cover data sets to develop region-specific land transformation elasticities that were used in the development of the 2013 GTAP results used in CCLUB. One data set allows determination of changes in agricultural land area. Based on this data set, the authors categorized GTAP regions (See Section 4) as having a low, medium, or high land transition elasticity. Taheripour and Tyner (2013) used the second data set to characterize changes in harvested areas among crop types. They used it to develop land transformation elasticities among crops. The United States was characterized as having low rates of land transformation overall, but high transformation elasticity among crops. Taheripour and Tyner (2013) found that the United States moved a sizeable amount of agricultural land to produce corn and oilseed crops without significant expansion in overall agricultural land.

The second change in GTAP between the 2011 and 2013 modeling exercises is the treatment of the costs of converting pasture and forest to cropland. In 2011, the cost of conversion of both of these land types to cropland was identical. Taheripour and Tyner (2013) modified the land nesting structure in GTAP to reflect the greater cost of conversion of forest to cropland as compared to converting pasture to cropland that is generally observed in the real world. This change essentially makes it more costly to convert forest to cropland than in the 2011 GTAP version.

GTAP permits three land types to be tapped for biofuel production: forest, grassland, and feedstock lands. The latter is agricultural land that has been converted to agriculture dominated by the production of biofuel feedstocks. In a differently nested category the model also accesses a fourth land type: cropland-pasture. Figure 2 illustrates the land transitions considered in CCLUB.

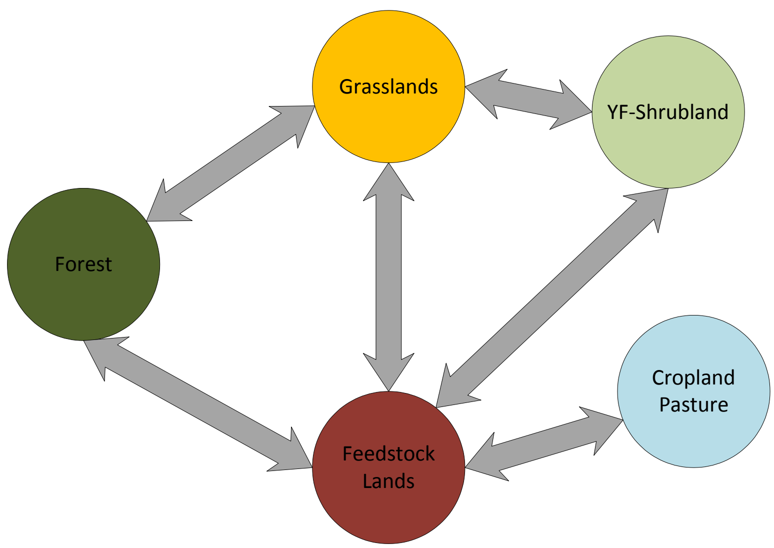

Figure 2. Land Transitions Modeled in CCLUB. Arrows indicate land use change directions.

Upon receiving the GTAP data from Purdue we, along with collaborators at the University of Chicago, compared the GTAP land database with both the National Land Cover Datasets (NLCD), which are part of the USDA Cropland Data Layers (CDL), and the US Forest Service's Forest Inventory data. We aimed to align forest area in the U.S. in our analysis with this database because we used Forest Service data to develop emission factors for aboveground and belowground carbon in addition to values for foregone sequestration. We therefore needed to reconcile forest area in the NLCD with forest area in GTAP.

The NLCD for 2006 put forest area at 207 million hectares (ha) for the lower 48 states. Including woody wetlands would bring this number up to 240 million ha. This figure is similar to the forest area from the USDA Forest Service's Forest Inventory Data Online (FIDO) database of 254 million ha. If we add forested area in Alaska, the total forest area rises to 285 million ha. However, the GTAP database includes a significantly higher value (370 million ha) for total forested land than these other data sources (see Table 3).

Table 3. GTAP vs. CDL Forest Area Comparison

AEZ	CDL Forest Area (ha)	GTAP Forest Area (ha)	CDL Accessible Forest Area (ha) (CLD_a)	GTAP Accessible Forest Area (ha) ($GTAP_a$)	Proration Factor ($CDL_a/GTAP_a$)
7	47,405,654	8,565,128	4,916,174	3,855,223	1.28
8	17,272,038	16,811,112	3,249,339	7,568,672	0.43
9	10,321,261	10,603,159	4,877,404	4,774,257	1.02
10	57,660,896	68,714,584	38,053,673	51,625,425	0.74
11	49,317,712	56,696,608	41,537,500	41,732,227	1.00
12	48,740,427	69,617,736	41,543,291	53,074,258	0.78
13	10,325,263	17,098,376	2,860,066	7,697,724	0.37
14	24,624,059	61,735,484	10,557,947	27,793,441	0.38
15	18,497,217	55,407,136	9,066,574	24,948,026	0.36
16	780,733	5,180,770	361,713	2,332,297	0.16
Total	284,945,260	370,430,093	157,023,681	225,401,549	0.70

Of the total forest area in both the CDL and GTAP data, some is inaccessible for biofuel production (national and state forest) and the remainder is accessible. Purdue provided the total split between accessible and inaccessible forest land in GTAP with accessible forest land accounting for 225 million ha out of the 370 million total forest ha. Our analysis indicated that the GTAP database uses the methodology by Sohngen (2004) to derive accessible vs. inaccessible land ratios by agro-ecological zone (AEZ) and then applies these ratios to the GTAP forest areas by AEZ. The reproduced GTAP accessible forest land by AEZ is shown in Table 3. A map showing the distribution of AEZs in the United States is in Figure 3. In our CDL analysis, subtracting state and national forest areas from the CDL total forest area data yielded 157 million ha of accessible forest. Across most AEZs (but not all) this is substantially less accessible forest land than GTAP predicts.

Based on the differences in the amount of accessible forest lands estimated by GTAP and the CDL analysis we assume that some of the GTAP accessible forest land is shrubland rather than mature forest land. To address this issue and to be consistent with U.S. Forest Service data, we added young forest-shrubland (YF-Shrub) as a fifth land type. Shrubland is defined in the NLCD Classification as "areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall." To determine the amount of land classified as YF-Shrub, we applied a proration factor to the accessible forest land GTAP predicted to be converted. The proration factor is calculated at the AEZ level as the ratio of accessible forest land in the CDL database to accessible forest land in the GTAP database (see Table 3). For example, if in a certain scenario GTAP predicted the conversion of 10,000 ha of forest to feedstock lands in AEZ 14, applying the proration factor results in CCLUB modeling 3,800 ha and 6,200 ha of forest and YF-Shrub lands being converted, respectively. In two AEZs, the proration factor exceeds one. In that case, our approach increases the amount of mature forest that is converted and effectively decreases the amount of YF-Shrub that converts to feedstock production land.

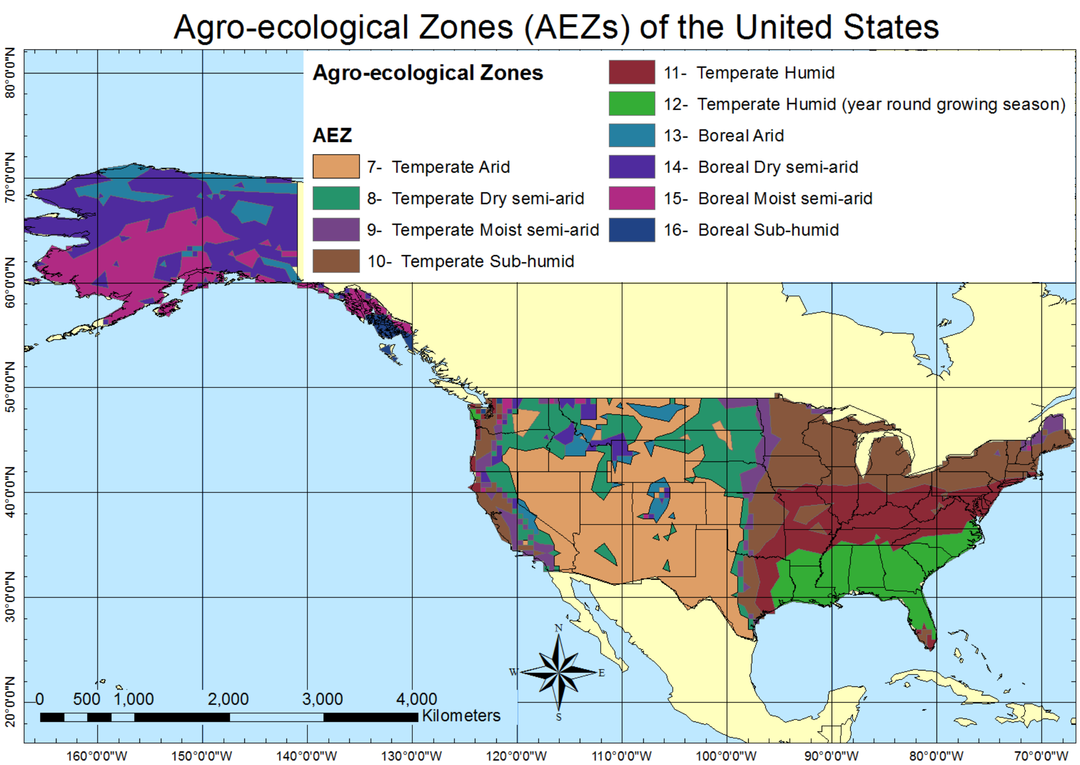

Figure 3. Distribution of AEZs in the United States

Converting YF-Shrub lands will have a lower carbon penalty than converting mature, carbon-rich forests. We therefore modified mature forest carbon emission factors to reflect this difference. The modified forest emissions factor for YF-Shrub is based on the relative height of forest stands in each state compared to shrubland. The relative tree heights for each state were derived from Pflugmacher (2008) and Buis (2012) (see Appendix A).

3. Belowground Carbon Data for the United States

This work took advantage of a surrogate model for CENTURY's soil organic carbon (SOC) sub-model (SCSOC) developed by Kwon and Hudson (2010). Use of CENTURY to estimate soil C stock change was logical as it is well-developed for croplands, grasslands, and forests (Parton *et al*. 1987, Paustian *et al*. 1992, Kirschbaum and Paul 2002) and can simulate land transitions incorporated in the GTAP modeling framework.

The SCSOC includes mass balance and decomposition kinetics equations for the three primary soil organic matter (SOM) pools (i.e., active, slow and passive SOM) described by CENTURY. Important differences between CENTURY and SCSOC are that SCSOC is coded and solved within the PROC MODEL of SAS (SAS Institute 2004) and decoupled from models of plant growth, nutrient cycling, and hydrologic processes described within CENTURY and associated variants. Use of the SCSOC provides the advantages of transparency and relative simplicity while allowing users to easily modify time-dependent CENTURY inputs. Important inputs to SCSOC include aboveground and belowground crop/plant C input rates to soil, and the site-specific decay rate coefficient of the SOM pools.

Overall, SOC modeling work in CCLUB builds on Kwon *et al*. (2013), in which the SCSOC model was used to derive emissions factors at the state level based on the scenarios that land presently in croplands, grasslands or pasture/hay (from this point on called grasslands), and forests could be converted to at least one of four likely biofuel (ethanol) feedstock production systems: corn-corn rotations, or corn-corn rotations with stover harvest, switchgrass, and *Miscanthus*. To anticipate soil carbon emissions from agricultural lands set aside for conservation, croplands/conservation reserve modeling scenarios considered lands that had never been cropped (grasslands) and that had reverted to grasslands after a period of cropping.

The 2014 CCLUB release contains significant SOC modeling updates. First, two new feedstocks, poplar and willow, have been included. It is important to note that CCLUB does not generate LUC GHG emissions for biofuels produced from these feedstocks because no GTAP modeling exercises have been completed to reflect those scenarios. The SOC emissions factors in CCLUB for these two feedstocks can be used to estimate direct GHG emissions associated with conversion of forest, cropland-pasture, cropland, and grassland to produce these feedstocks. Combining original land use, feedstock type, and land management practice resulted in 40 general LUC scenarios to consider for soil carbon emissions. The transitions are diagrammed in Figure 4 and presented in tabular format in Appendix B. The scenario numbers in Appendix B identify these scenarios within CCLUB.

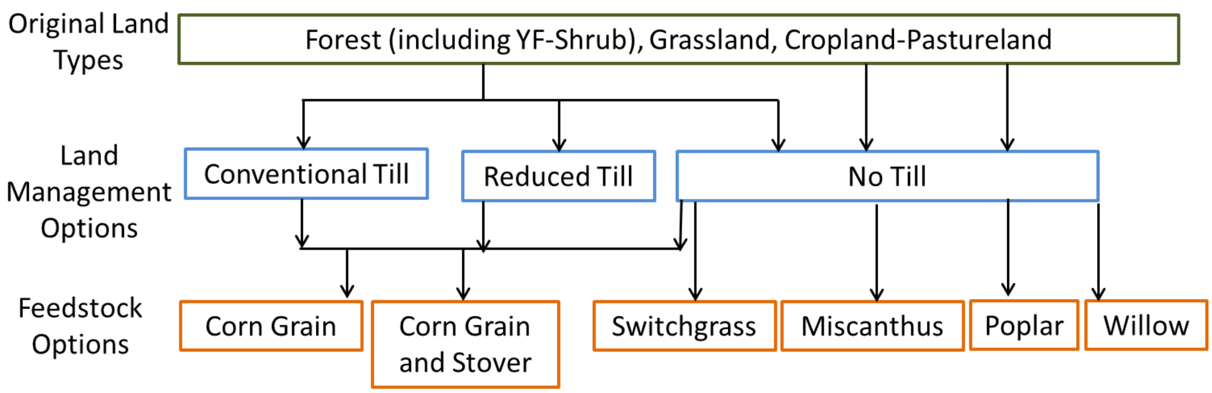

Figure 4. Soil Carbon LUC Scenarios Modeled in CCLUB

The second significant update to CCLUB is that SOC results for a soil depth of 100 cm have been added. We expanded CCLUB to include these results because, although most farming activity directly disturbs soils to 30 cm, SOC changes at 100 cm can still occur and influence the overall SOC implications of LUC (Qin *et al*. 2014). CCLUB still contains results for SOC changes at 30 cm. As with previous releases, all modeling results are at the county level. For this analysis, inputs to the SCSOC model include county-level edaphic characteristics, climate data, and biomass estimates. We identified the most prevalent land use categories present within each county using remote sensing analysis of the National Land Cover Database 2006 (NLCD) reported by Fry *et al*. (2011). Then we identified soil texture classes (e.g. sand, clay, and loam) of the Harmonized World Soil Database (HWSD) within each land use category. The monthly temperature and precipitation data used to calculate the effects of weather were from weather station data between 1960 and 2010 reorganized to the county level.

All SOC modeling scenarios include the effects of erosion. They use the average soil loss or erosion rates (Mg soil ha^{-1} yr^{-1}) for croplands and pasture/hay/grasslands were obtained from the National Resources Inventory (NRI) erosion estimates (USDA-NRCS), which are based upon the Universal Soil Loss Equation and Wind Erosion Equation (for wind erosion), by averaging periodic erosion estimates from 1982, 1987, 1992, 1997, 2002, and 2007. For forests and land used for either switchgrass or *Miscanthus*, we assumed zero soil erosion rates. Under a no-erosion scenario we assumed zero soil erosion rates for the croplands and pasture/hay/grasslands as well.

It is important to note that the soil carbon decay coefficients in CENTURY for corn agriculture were adjusted from default values because several studies have shown that CENTURY soil decay coefficients need to be adjusted upward to properly estimate soil organic carbon (SOC) levels under row-cropped systems (Carvalho Leite *et al*. 2004; Matthews and Pilbeam 2005). Dunn *et al*. (2013) reported the influence of using the calibrated value of this parameter and the inclusion of erosion in SOC modeling on LUC GHG emissions.

CCLUB includes two basic yield scenarios: a constant yield and a yield increase scenario. Note that GTAP simulations did not incorporate crop yield increases for any of the feedstocks. To estimate the yields for major crops (i.e. corn, soybean, and wheat), we used the historical records of crop yields surveyed by USDA-NASS accessed through QuickStats. Eaton of Oak Ridge National Laboratory provided county-level yields of switchgrass, *Miscanthus*, and poplar based on PRISM-EM modeling (Eaton 2014). Yields of these feedstocks were calculated in a consistent manner with the methods used in the Billion-Ton Study (U.S. Department of Energy 2011). To estimate corn yields for the corn-corn scenarios, we used state-level corn yield records during the early agricultural period (1880 – 1950) and county-level corn yield records for the modern agricultural period (1951 – 2010) (Appendix B). All the records were obtained from USDA-NASS QuickStats. Future corn yield assumptions (2011-2040) included a constant yield case based on the 20 yr-average of county-level corn yields (1991 – 2010) and a yield increase case based on a simple regression equation derived from each county's corn yield records of modern agricultural period (Kwon *et al*. 2013). It was assumed that the harvest index (ratio of stover to corn grain) and the root-to-shoot ratio would be constant into the future. This method is consistent with the approach used by Miranowski *et al*. (2011) who used linear regression to predict yield trends although on a state level. For some counties, insufficient corn yield data were available to generate results. At this time, CCLUB does not include results for these counties. The yield increases for *Miscanthus* and switchgrass were projected to be 1% annually, which is more conservative than the recent update of the Billion-Ton Study (U.S. Department of Energy 2011), which considered annual yield increases of 2%, 3%, and 4%.

Corn-based systems were simulated with three different tillage options [i.e., conventional tillage (CT), reduced tillage (RT), and no tillage (NT)] while the two perennial grass systems were simulated with NT. Under regular tillage 95% surface residue is assumed to be mixed to soils, under reduced tillage 30% is mixed to soils, and under no-tillage 5% is mixed to soils. Stover harvest rates were set at 30% to avoid increasing soil erosion or diminishing soil fertility (Nelson 2002; Wilhelm *et al*. 2004; Johnson *et al*. 2006; Simon *et al*. 2010a). To leave similar amounts of aboveground residues in place and thus avoid soil depletion, a 90% biomass harvest rate was used for switchgrass and *Miscanthus* (Eaton 2014). Table 4 summarizes key modeling parameters for each feedstock.

Table 4. Key Parameters Used in the SCSOC Model for Corn, Switchgrass, *Miscanthus*, Poplar and Willow.

	HI[1]		RS[2]	Aboveground biomass return[3]	TILL[4]
	1880-1950	1951-2040			
Corn	0.35	0.53	0.55	0.7, 1.0	NT, RT, CT
Switchgrass			1.00	0.1	NT
Miscanthus			1.00	0.1	NT
Poplar			2.00	0.1	NT
Willow			2.00	0.1	NT

[1]HI, harvest index for historical (1880-1950) and modern (1951-2040) land use periods (Vetsch & Randall; Allmaras *et al.*, 1998; Prince *et al.*, 2001; Halvorson *et al.*, 2002; Pedersen *et al.*, 2004). [2]RS, root to shoot ratio (Buyanovsky & Wagner, 1986; Ojima *et al.*, 1994; Dohleman, 2009; Garten Jr. *et al.*, 2010; Pacaldo *et al.*, 2013; Garten Jr. *et al.*, 2011); for poplar and willow, the root includes total belowground biomass and aboveground stool. [3]Return rate for aboveground biomass (Kwon *et al.*, 2013; Eaton, 2014); for corn, the aboveground biomass return rate has two options in the model. [4]TILL, tillage options in the model (Kwon *et al.*, 2013). Most parameters for corn, switchgrass and *Miscanthus* were inherited from the previous version of SCSOC (Kwon *et al.*, 2013).

In summary, CCLUB users can model SOC changes at the county level resulting from the land transitions in Figure 4 at either a 30 cm or 100 cm soil depth and with or without yield increase. In CCLUB, county-level SOC changes are grouped by AEZs then averaged to provide the value for a given scenario in that AEZ. In future CCLUB releases, we may use an area-weighted average based upon county area or other weighting approaches.

Alternatively, CCLUB can be parameterized with direct emissions factor sets from the Woods Hole Research Center, which was originally authored by R. Houghton and provided to the California Air Resources Board and GTAP in support of land use modeling efforts, or from Winrock (Harris *et al*. 2009). The Woods Hole emissions factor dataset is reproduced in Tyner (2010). Woods Hole factors are not available by AEZ but are at the biome level. Winrock provides carbon stock data at the state level; the average of these values is used in CCLUB.

4. Non-soil Carbon Data for the United States

Non-soil carbon from forest ecosystem conversions is based on COLE (Van Deusen and Heath 2010, Van Deusen and Heath 2013). In order to determine non-soil carbon impacts of forest-to-cropland conversion scenarios we accessed the county-by-county data for the five different non-soil components: aboveground live tree carbon density, aboveground dead tree carbon density, understory carbon density, forest floor carbon density, and coarse woody debris carbon density.

Foregone sequestration from annual biomass growth is based on the COLE value for net annual growth. In time, some feedstock production land may revert back to forest land. Reversion non-soil carbon factors are also based on COLE's net annual growth. The emissions/sequestration effects from root biomass are included in the boundary of the CENTURY modeling runs. It is important to note that this approach provides consistency of data sources throughout CCLUB: the spatially explicit US Forest Service COLE data is used for aboveground carbon stocks, the corresponding root biomass values (corresponding to the aboveground carbon values) are used to parameterize CENTURY, and finally the predicted GTAP transitions are adjusted to match the US Forest Service forest area (via the forest proration factor described in Section 2).

The carbon in some harvested wood will not be emitted, but contained within harvested wood products (HWP) in productive uses such as buildings. Based on Heath *et al*. (1996) and a follow-up conversion with Heath we determined that 60% of the combined aboveground live and dead tree carbon density can be removed from the forest. 35% of this carbon is stored in products and an additional 35% is converted into useful energy (both considered harvested wood product offsets). The carbon in the remaining aboveground categories is assumed to be released to the atmosphere as is carbon in the waste wood. Figure 5 depicts the fates of aboveground live and dead tree carbon based upon Heath *et al*. (1996). Alternatively, the CCLUB user has the option to exclude any HWP offsets (HWP set to zero).

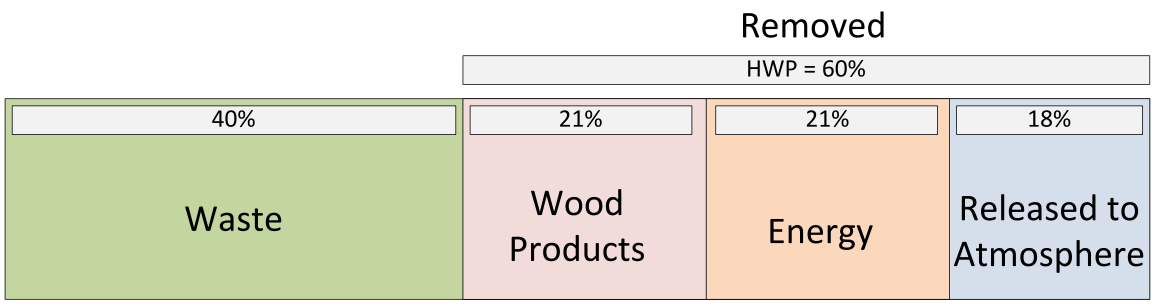

Figure 5. Fate of Aboveground Live and Dead Tree Carbon

For the emissions assessments based on the Woods Hole dataset (direct and indirect), the amount of aboveground carbon emitted to the atmosphere is 75%. CCLUB users can adjust this factor in the respective sections of the Direct C-Factors and Indirect C-Factors worksheet (in the column titled "C Released During Conversion"). Winrock, in developing their carbon stock values, assumed no carbon is sequestered in HWP (Harris *et al*. 2009).

All GTAP results are based on AEZs. We therefore aggregated the higher resolution county-level factors to match the AEZ regions. AEZ-level factors were derived as average of county-level factors. As with the belowground carbon county-level to AEZ aggregation, we may use different aggregation techniques in future CCLUB releases.

5. Indirect (International) Emission Factors

The primary indirect emissions assessment in CCLUB is based on carbon content data for international lands obtained from Winrock International (Harris *et al*. 2009). These data were developed for US EPA's Renewable Fuel Standard (RFS) and accompanying analysis of life-cycle GHG emissions of biofuels, including from LUC. CCLUB uses the modifications to the

Winrock factors that EPA adopted in modifying their analysis between the proposed and final versions of RFS2.

Winrock used recent land cover products derived from satellite imagery and other data sources and developed GHG emission factors for various land cover conversions. They report one emission factor per country, and for some countries for administrative units, over a 30-year time period. This time period matches the time horizon used to develop domestic emission factors as described in Section 3. The Winrock 30-year emission factors are calculated with emission factors developed for three different periods following the land transition as described in Equation 1.

$$EF_{30} = EF_1 + 19 \times EF_{2-19} + 10 \times EF_{20-80} \qquad [1]$$

where

EF_{30} = GHG emissions 30 years after the transition [Mg CO_2e/ha];

EF_1 = GHG emissions in the first year after the transition [Mg CO_2e/ha];

EF_{2-19} = GHG emissions in years 2 through 19 after the transition [Mg CO_2e/ha]; and

EF_{20-80} = GHG emissions in years 20 through 80 after the transition [Mg CO_2e/ha].

Complete details of the development of the Winrock emission factors are contained in Harris *et al*. (2009) but we summarize a few salient points in Table 5.

In the Winrock data set, with the exception of reversion to forests, reversion emission factors are estimated as the reverse of emission factors with all biomass carbon stock increases occurring in the first year after reversion. Soil carbon stock changes on abandoned cropland, however, take 20 years to reach pre-conversion values.

In the case of croplands that revert to forests, biomass accumulates annually over the 30-year reversion period. To be conservative, Winrock assumed that the newly growing trees accumulate carbon at the foregone sequestration rate. In reality, these young trees would incorporate carbon at a faster rate than the trees in more established forests that may have been cleared for feedstock production. Further details on these calculations are available in Harris *et al*. (2009).

The Winrock data set does include estimates of uncertainty for these emission factors, which we may include in a future release of CCLUB.

Table 5. Data Sources and Key Methodology Points for Winrock Emission Factors

Land Type	Forest	Grassland	Cropland Pasture[2]
Data source	Figure 3 in Harris *et al.* (2009) shows a world map color-coded to indicate the data source for each region.	Data for Brazilian grasslands based on a number of data sources. For all other countries, estimates based on Table 6.4 of the IPCC AFOLU[1] Guidelines	Calculated as the average of forest, shrubland, grassland, and cropland carbon stocks.
Key methodology points	Includes CH_4 and N_2O emissions from forests cleared by burning. No carbon is assumed to be sequestered in harvested wood products. Foregone sequestration is included based on several literature reports.	Outside of Brazil, ratios of savanna and shrubland areas were calculated from grasslands based on the ratios of areas of these land types from the Brazilian data set	Follows International Geosphere-Biosphere Programme (IGBP) land cover definitions

1. Agriculture, Forestry, and Other Land Use. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html
2. CCLUB assigns emission factors the "Mixed" category from Winrock, which consists of a crop and vegetation mosaic, to international cropland pasture areas undergoing LUC as predicted by GTAP.

To incorporate these emission factors into CCLUB, we combined emission factors for countries that are included in the categories in which GTAP results are reported. Table 6 lists these categories and the countries that are included in each. We used a simple average of the emission factors for these countries. In the future, we may assess other approaches such as weighting a country or region's emission factor by its area.

Some countries within the Winrock data set were not included. One reason for exclusion was that some countries are very small and because we did not weight countries' emission factors, a small country could alter the average to a value uncharacteristic of the region. Additionally, if a country is primarily desert, such as Syria, we excluded it.

CCLUB also includes the Woods Hole data set. Users can select either the Winrock or Woods Hole data set to estimate international LUC GHG emissions.

Table 6. Aggregation of Countries in Winrock Data Set to GTAP Regions. An asterisk indicates subregions of the country were included in the average.

Region	GTAP Code	Countries Included
United States[1]	US	United States*
European Union	EU 27	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Germany, Spain, Estonia, Finland, France, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovenia, Romania, Slovakia, Sweden, United Kingdom
Brazil	Brazil	Brazil*
Canada	Canada	Canada*
Japan	Japan	Japan
China	CHIHKG	China*
India	India	India*
Central America	C_C_Amer	Belize, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Mexico*, Nicaragua
South America	S_o_Amer	Colombia, Argentina*, Bolivia, Chile, Paraguay*, Peru, Uruguay, Venezuela
East Asia	E_Asia	North Korea, Mongolia, South Korea, Taiwan
Malaysia and Indonesia	Mala_Indo	Indonesia*, Malaysia*
Rest of Southeast Asia	R_SE_Asia	Philippines*, Singapore, Thailand*, Vietnam*
Rest of South Asia	R_S_Asia	Bangladesh, Cambodia, Pakistan, Sri Lanka
Russia	Russia	Russia*
Other Eastern Europe and Rest of Former Soviet Union	Oth_CEE_CIS	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Croatia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkey, Turkmenistan, Uzbekistan
Middle East and North Africa	MEAS_NAfr	Afghanistan, Algeria, Egypt, Ethiopia, Iran*, Iraq, Israel, Liberia, Libya, Morocco, Oman, Saudi Arabia, Tunisia
Sub Saharan Africa	S_S_AFR	Angola, Botswana, Cameroon, Central African Republic, Democratic Republic of the Congo, Ghana, Guinea, Kenya, Madagascar, Malawi, Mozambique, Namibia, Nepal, Nigeria*, Senegal, Somalia, South Africa*, Tanzania, Togo, Uganda, Zambia, Zimbabwe

1. Winrock data for the U.S. are only used in CCLUB if the user selects that data set for the domestic emissions modeling scenario.

6. Temporal Issues in Modeling LUC Emissions

CCLUB's assessment of carbon emissions from LUC depends on two critical time horizons: the duration of biofuels production and the emissions amortization period. Assumptions regarding the duration of biofuels production impact foregone sequestration from annual biomass growth and the associated soil carbon adjustments. Since the data set on soil carbon adjustments from the CENTURY model and the Winrock international carbon emission factors are based on 30-year equilibrium values, the production duration should not be varied significantly from that value. We assume that a relatively small variation of ±5 years may not introduce significant errors. The emissions amortization period refers to the duration over which a biofuels policy is analyzed.

7. Using CCLUB

In this section, we explain the contents of the eight sheets that make up CCLUB. We describe them in order of calculation flow rather than the left-to-right progression of sheets.

7.1. Overview Worksheet

This sheet contains author information and a list of worksheets and their descriptions.

7.2. Scenario and Results Worksheet

This sheet contains seven user inputs and a results section. Users select input values in the rose-colored cells. All options are visible in the yellow cells in each section. The first user input (Input 1) is the feedstock-to-fuel pathway. The user can choose from among the biofuel scenarios in Table 2 of this document, which include corn and cellulosic ethanol options (corn stover, *Miscanthus*, or switchgrass feedstocks).

The second user input is the scenario selection for domestic (direct) emissions scenarios (Input 2a). The data underpinning these scenarios is described in Sections 3 and 4. If the user opts to include domestic SOC emission factors from CENTURY modeling, he or she must choose whether to use modeling results that take into account yield increases (Input 2b) and select a soil depth (30 or 100 cm) as Input 2d. The land management practice options that constitute Input 2c allow the user to assess the influence of tillage practice on the results for corn and corn stover pathways. For input 3, users choose between Winrock and Woods Hole data sets for international LUC emissions (Input 3).

The user selects an HWP scenario for Input 4, either using the assumptions of Heath *et al*. (1996) or assuming all aboveground carbon is emitted when forests are converted to biofuel feedstock production.

In developing CCLUB, we modified GTAP data for area of converted forest as described in Section 2. Input 5 allows CCLUB users to adopt adjustments to converted forest lands by selecting "Yes" or to use raw GTAP data by selecting "No."

Users can alter the foregone carbon sequestration period by adjusting Input 6. Users are cautioned, however, that the modeling runs that produced domestic soil carbon values and Winrock emission factors are based on 30 year time horizons. Choosing values outside that time window may produce inaccurate results.

Finally, users can alter the amortization period in Input 7. See Section 6 for a discussion of how amortization influences results.

Once all inputs are selected, the user can click on the "Run Simulation" button and view results within CCLUB as described in the following paragraph. If the user also clicks on "Copy to GREET," inputs and results will be transferred to GREET and incorporated into overall biofuel life cycle analysis. The user will have an active GREET spreadsheet after clicking this button.

No input or adjustments are required on other sheets to see the results, which vary based on the user selection in the Inputs section. Emissions are divided into land types of forest, grassland, cropland-pasture, and young forest-shrub. Note that Woods Hole data does not include the latter two land types. Just to the right of the main results table, results are tabulated for all data set options within CCLUB. In this section, the emissions are divided into direct and indirect emissions, each of which are broken out as follows by land type.

- Direct or Indirect Emissions (Mg C): Total carbon emissions for the selected scenario by land type

- Direct or Indirect Emissions (Mg CO_2e): The total carbon emissions are converted to carbon dioxide equivalent emissions (3.67 g CO_2/g C)
- Direct or Indirect Annualized Emissions (Mg CO_2e/yr): The total carbon dioxide emissions are divided by the amortization period specified in Input 7
- Direct or Indirect Annualized Emissions (g CO_2e/gal): The annualized emissions are divided by the annual fuel production volume
- Direct or Indirect Annualized Emissions (g CO_2e/MJ): The volume-based emissions are converted to a unit energy basis with the lower heating value of ethanol.

The red highlighted box in the Results section contains the total LUC GHG emissions associated with the selected scenario in units of g CO_2e/MJ.

7.3. GTAP Data Worksheet

This worksheet contains three sections. The bottom section with a heading of "GTAP Source Data Tables" contains the raw GTAP data generated as described in Taheripour *et al*. (2011) and Taheripour and Tyner (2013). The data are grouped by scenario. The section above the raw data, entitled "Land Use Summary by Region and AEZ" selects the LUC data from the appropriate scenario. The top section, "Land Use Summary by Region," contains the total of LUC by land type and country/region. These values are multiplied by the appropriate emission factors to generate LUC emissions results.

7.4. C-Database Worksheet

In this worksheet, soil organic carbon change data from the CENTURY model are included for every scenario at the county-level. As described above, for some counties it was not possible to estimate SOC changes. County-level COLE data for aboveground carbon are also included in this worksheet to the right of county-level SOC data. SOC and aboveground carbon for each county is averaged by AEZ in the table at the top of the worksheet for use on the Direct C-Factors worksheet.

It is important to note the sign convention for this worksheet. CENTURY results are included as the change in soil carbon stock for each county. If SOC in the land's final state is greater than in its initial state, the SOC change will be positive. In this case, biofuel feedstock production has benefited SOC. If the land transition results in a decrease in SOC, SOC has been depleted as a result of the land transition and the SOC change will be negative.

7.5. Direct C-Factors Worksheet

This worksheet displays the direct carbon factors based on CENTURY/COLE and the direct carbon factors based on Woods Hole. This sheet uses color coding to guide the user’s eye. Soil and non-soil carbon stock changes are red- and blue-highlighted, respectively. Annual growth values are green-highlighted.

The first table contains soil carbon stock changes by AEZ as modeled in CENTURY and described in Section 3. Separate tables are provided for each scenario option in Input 2.

The second table contains non-soil carbon by AEZ, developed as explained in Section 4. Note that only aboveground carbon emission impacts of forest conversion are considered because belowground carbon stock changes (from soil and tree roots) are considered in CENTURY. In this table, the YF-Shrub correction factor described in Section 2 is also calculated.

The third table contains data from COLE for total net tree growth. The values stated in Mg carbon per hectare per year are calculated from the carbon contained in that new tree growth using a forest carbon factor of 50%, which is consistent with the IPCC Good Practice Guidance For Land Use, Land Use Change and Forestry (IPCC, 2003).

Section B and Section C of this sheet contains the Woods Hole and the Winrock direct emissions factors, respectively and calculates emission factors.

7.6. Indirect C-Factors Worksheet

This sheet has the same color scheme as the Direct C-Factors sheet. It calculates indirect emissions factors from the Winrock and Woods Hole data sets, which are described in Section 5.

7.7. Forest Land Area Worksheet

Section A of this sheet contains state-level land use data from CDL analysis that is mapped to the AEZ level using the matrix displayed in Section B. Forest proration factor calculations are in Section C of the sheet. Section 2 of this document discusses these calculations.

7.8. Modeling Worksheet

At the top of this sheet, conventions used in calculations are defined. Carbon emission and sequestration factors are defined as positive and negative, respectively. Converted land areas are treated as negative whereas reverted lands are defined as positive. The color coding of the spreadsheet is also defined. Soil and non-soil emissions factors are highlighted in red and blue, respectively. The annual growth of forests is highlighted in green. Land areas imported from other tabs are colored gray.

The first data section in the sheet contains direct emissions based on data from the CENTURY modeling effort described in Section 3. Modeling is grouped as follows. First emissions factors for conversion and reversions of forests, grasslands, YF-shrublands, and cropland-pasture lands (as Figure 2 depicts) are calculated as the sum of aboveground carbon, soil carbon, and foregone sequestration from annual growth. Note that the soil carbon emissions factors for the corn ethanol and stover ethanol scenarios are dependent on the selected tillage scenario (CT, RT and NT). In a second step those emissions factors are matched to the selected biofuels scenario and multiplied by the corresponding GTAP land area changes for each transition. It is in this sheet that the forest proration factor is applied.

Direct emissions calculated with Woods Hole and Winrock emissions factors are also displayed in this sheet in Sections A.2 and A.3.

The international components of the Woods Hole and Winrock emissions factor data dataset described above are used to assess indirect emissions for the selected biofuels scenarios in Sections B and C.

7.9. Selected Results and Outstanding Issues

The results for one likely parameterization scenario of CCLUB are shown in Table 7. In this scenario we have selected CENTURY-based soil carbon factors reflective of projected yield increases and a 100 cm modeled soil depth combined with aboveground carbon factors based on USDA Forest Service COLE data. Furthermore, for domestic emissions we have adjusted the GTAP results with YF-Shrub transitions. We have included HWP factors based on Heath *et al* (1996). International emissions were calculated with the Winrock data set. The chosen scenario would indicate that ethanol production from corn stover and switchgrass would not result in any significant LUC GHG emissions. If *Miscanthus* is the selected ethanol feedstock, LUC results in net carbon sequestration. Corn ethanol production would result in net positive LUC GHG emissions (with less emissions under no-till management). Dunn *et al*. (2013) explored how results vary with different modeling options, but used the state-level SOC emission factors that the 2012 version of CCLUB contained. Table 7 also includes results using GTAP results from Taheripour and Tyner (2013) that used the refined GTAP version as described in Section 2. Using this version of GTAP reduced corn LUC GHG emissions by 3 g CO_2e/MJ.

It is important to note that GTAP modeling results for switchgrass and *Miscanthus* as ethanol feedstocks are largely driven by yield of these two crops which can in fact vary with location and management practices. Higher yielding biofuel feedstocks induce less LUC and therefore lower LUC GHG emissions. Results for *Miscanthus* and switchgrass ethanol can therefore be interpreted as representing results for high and lower yielding crops, respectively.

Table 7. Selected CCLUB Summary Results for Feedstock-to-Ethanol Pathways (g CO_2e/MJ)

	Emission Factor Source	HWP Factor	Corn 2011 CT	Corn 2011 NT	Corn 2013 CT	Corn Stover CT	*Miscan-thus*	Switch-grass
Direct (domestic) emissions	CENTURY/ COLE[b]	60%[a]	2.6	1.4	-1.9	-0.2	-22.3	-10.5
Indirect (international emissions)	Winrock	0%	5.0	5.0	5.1	-0.5	2.2	7.1
Total[c]			7.6	6.3	3.2	-0.7	-20.1	-3.5

a. Per Heath *et al*. as explained in Section 4
b. CENTURY/COLE modeling with yield increase at 100 cm soil depth
c. May not be the exact sum of domestic and international emissions due to rounding

In future work we intend to address several outstanding issues. For example, current SOC modeling of conversion to cropland assumes that cropland is essentially planted in corn, but GTAP results may indicate other crops could be planted as well as part of crop switching as discussed in Section 2. We may seek to model transitions to specific crop types beyond corn. Secondly, corn agriculture is currently modeled as continuous corn, but actual practice may be to integrate soy rotations. We will consider different rotation scenarios for inclusion in CCLUB. Finally, we currently model the land use history of cropland-pastureland as 50 years as cropland followed by 25 years of pasture and 25 years of cropland. Actual land use history may include more frequent changes between these two land uses. We may develop SOC emission factors for land transitions involving cropland-pastureland that reflect a more defined land use history.

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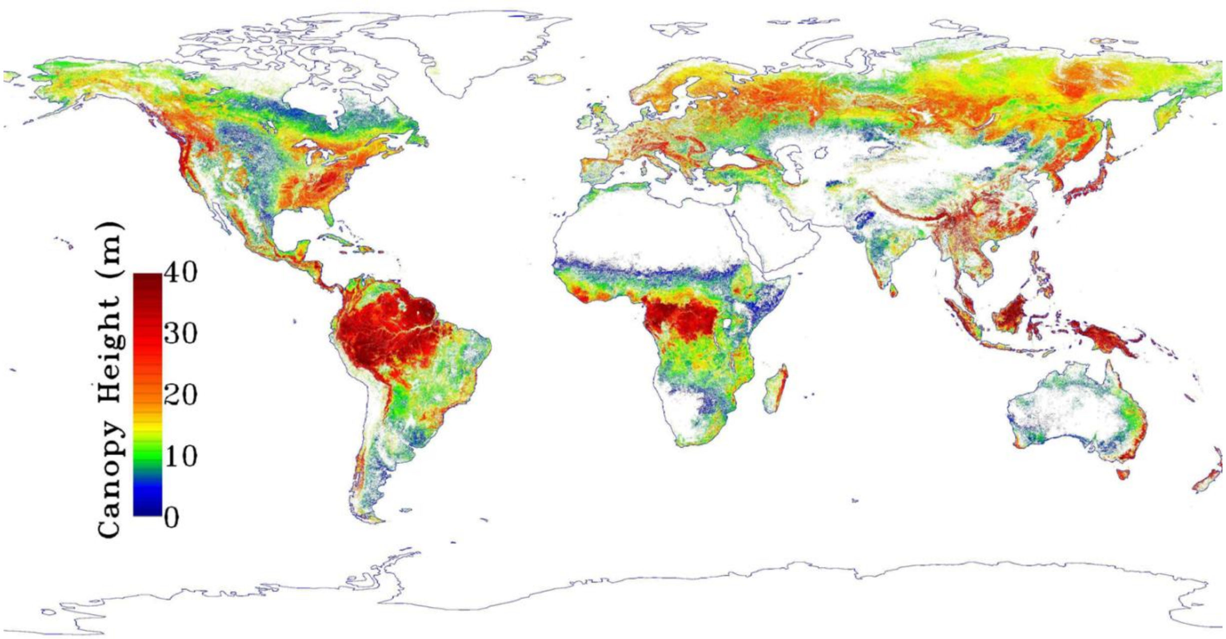
Appendix A: Global Map of Forest Height



Source: Alan Buis, Jet Propulsion Laboratory, Pasadena, Calif. Global map of forest height produced from NASA's ICESAT/GLAS, MODIS and TRMM sensors.

http://www.nasa.gov/topics/earth/features/forest20120217.html

Appendix B: Tabular Summary of Land Conversions

Scenario	Historic land use	1880-1950	1951-2010	2011-2040		
				Crop	Tillage	R (%)[1]
1	Grasslands	Croplands	Croplands	Corn	CT	0
2				Corn	CT	30
3				Corn	RT	0
4				Corn	RT	30
5				Corn	NT	0
6				Corn	NT	30
7				Switchgrass	NT	90
8				*Miscanthus*	NT	90
9				Poplar	NT	90
10				Willow	NT	90
11	Grasslands	Grasslands	Grasslands	Corn	CT	0
12				Corn	CT	30
13				Corn	RT	0
14				Corn	RT	30
15				Corn	NT	0
16				Corn	NT	30
17				Switchgrass	NT	90
18				*Miscanthus*	NT	90
19				Poplar	NT	90
20				Willow	NT	90
21	Forests	Forests	Forests	Corn	CT	0
22				Corn	CT	30
23				Corn	RT	0
24				Corn	RT	30
25				Corn	NT	0
26				Corn	NT	30
27				Switchgrass	NT	90
28				*Miscanthus*	NT	90
29				Poplar	NT	90
30				Willow	NT	90
31	Grasslands	Croplands	Grasslands (1951-1975)-Croplands (1976-2010)	Corn	CT	0
32				Corn	CT	30
33				Corn	RT	0
34				Corn	RT	30
35				Corn	NT	0
36				Corn	NT	30
37				Switchgrass	NT	90

Continued next page…

Continued

38	*Miscanthus*	NT	90
39	Poplar	NT	90
40	Willow	NT	90

[1]R is Residue or biomass removal rate (%) simulated in the model. This table contains 40 land conversions modeled in surrogate CENTURY. The results are contained in CCLUB.

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